**INTRODUCTION TO ICE CORE DATA: EVIDENCE FOR CLIMATE CHANGE**

Throughout much of its 4.5 billion year history, Earth’s climate has been in a state of fluctuation. Some eras were dominated by coldness while others were characterized by warmth. Some of these periods included drastic fluctuations while others remained fairly stable for millions of years.

Four major continental glaciations are recorded in North America. The last (Wisconsin) began about 70,000 years ago and ended 10,000 years ago. Much of Wisconsin’s geological landscape was influenced by glaciation. The northern half of the state is mixed hardwood and coniferous forests. Farmland and prairies exist primarily in the southern half where the glaciers dropped sediment that made the land nutrient rich. The bluffs and narrow valleys of the Driftless Area, in the south -western corner of the state, are places where the last glaciers did not reach and, thus, the landscape was not scraped or leveled.

The polar regions of the world have held ice throughout and between these glacial periods. Like rings of trees in temperate parts of the world, ice layers in polar regions and glaciers also create layered historical records. Layers of snow become compacted into ice, which are laid atop previous layers of ice to create these records of the past.

To analyze historical climate changes, scientists drill down into the ancient ice where information about the atmosphere has been captured. Scientists extract the ice core and use it to analyze atmospheric physical and chemical characteristics to create scientific snapshots of Earth during single points in time. Small bubbles in the ice hold trapped atmospheric gases from hundreds of thousands of years ago. When scientists analyze the composition of those trapped gases they are measuring the concentrations of gases in Earth’s atmosphere when each layer was formed, including the concentration of carbon dioxide (CO2), a green house gas. In addition, the water in each layer of the ice holds oxygen and hydrogen isotopes. The relative concentrations of these isotopes will vary depending on the temperature when the layer was created. Thus, the scientists are able to determine the historical record of the temperature as well.

Perhaps the most famous study of this type is the Vostok ice cores from Antarctica. These data are often cited in climate change articles. By showing a correlation between global temperatures and atmospheric CO2 levels, scientists find evidence that changing the concentration of CO2 in the atmosphere can change the global temperature and climate.

**Paleoclimatology: The Ice Core Record**

by Holli Riebeek· design by Robert Simmon· December 19, 2005

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Richard Alley might have envied paleoceanographer Jerry McManus’ warm, ship-board lab. One of the researchers in the Greenland Ice Sheet Project 2 (GISP2), Alley huddled in a narrow lab cut into the Greenland Ice Sheet, where “the temperature stayed at a ‘comfortable’ twenty below [Fahrenheit],” he wrote in his book about his research, The Two-Mile Time Machine. An assembly line of science equipment lined the twenty-foot-deep trench that served as a makeshift lab. For six weeks every summer between 1989 and 1993, Alley and other scientists pushed columns of ice along the science assembly line, labeling and analyzing the snow for information about past climate, then packaging it to be sent for further analysis and cold storage at the National Ice Core Laboratory in Denver, Colorado. Nearby, a specially built drill bored into the thick ice sheet twenty-four hours a day under the perpetual Arctic sun. Essentially a sharpened pipe rotating on a long, loose cable, the drill pulled up cores of ice from which Alley and others would glean climate information.

Throughout each year, layers of snow fall over the ice sheets in Greenland and Antarctica. Each layer of snow is different in chemistry and texture, summer snow differing from winter snow. Summer brings 24 hours of sunlight to the polar regions, and the top layer of the snow changes in texture—not melting exactly, but changing enough to be different from the snow it covers. The season turns cold and dark again, and more snow falls, forming the next layers of snow. Each layer gives scientists a treasure trove of information about the climate each year. Like marine sediment cores, an ice core provides a vertical timeline of past climates stored in ice sheets and mountain glaciers.

The seasonal snow layers are easiest to see in snow pits, writes Alley, the Evan Pugh Professor in the Environment Institute and Department of Geosciences at Pennsylvania State University. To see the layers, scientists dig two pits separated by a thin wall of snow. One pit is covered, and the other is left open to sunlight. By standing in the covered pit, scientists can study the annual snow layers in the snow wall as the sunlight filters through the other side. “I have stood in snow pits with dozens of people—drillers, journalists, and others—and so far, every visitor has been impressed. The snow is blue, something like the blue seen by deep sea divers, an indescribable, almost achingly beautiful blue,” writes Alley. “The next thing most people notice is the layering.”

To pry climate clues out of the ice, scientists began to drill long cores out of the ice sheets in Greenland and Antarctica in the late 1960s. By the time Alley and the GISP2 project finished in the early 1990s, they had pulled a nearly 2-mile-long core (3,053.44 meters) from the Greenland ice sheet, providing a record of at least the past 110,000 years. Even older records going back about 750,000 years have come out of Antarctica. Scientists have also taken cores from thick mountain glaciers in places such as the Andes Mountains in Peru and Bolivia, Mount Kilimanjaro in Tanzania, and the Himalayas in Asia.

The ice cores can provide an annual record of temperature, precipitation, atmospheric composition, volcanic activity, and wind patterns. In a general sense, the thickness of each annual layer tells how much snow accumulated at that location during the year. Differences in cores taken from the same area can reveal local wind patterns by showing where the snow drifted. More importantly, the make-up of the snow itself can tell scientists about past temperatures. As with marine fossils, the ratio of oxygen isotopes in the snow reveals temperature, though in this case, the ratio tells how cold the air was at the time the snow fell. In snow, colder temperatures result in higher concentrations of light oxygen.

Scientists can confirm these chemistry-based temperature measurements by observing the temperature of the ice sheet directly. The ice sheet’s thickness makes its temperature much more resistant to change than the six inches of snow that might fall on your driveway during a winter snowstorm. As Alley explained to the Earth Observatory, the ice sheet can be compared to a frozen roast that is put directly into the oven. The outside heats up quickly, but the center remains cold, close to the temperature of the freezer, for a long time. Similarly, the ice sheet has warmed somewhat since the Ice Age, but not completely. The top has warmed as global temperatures have warmed, while the bottom has been warmed by heat flow from deep inside the Earth. But in the middle of an ice sheet, the ice remains close to the Ice Age temperatures at which it formed. “Because we understand how heat moves in ice, [and] we know how cold the ice is today, we can calculate how cold the ice was during the Ice Age,” says Alley.

When scientists lower an ultra-precise thermometer into a hole in the ice, they can detect the temperature variations that have occurred since the Ice Age. The near-surface ice temperature, like the atmosphere today, is warm, and then the temperature drops in the layers formed roughly between AD 1450 and 1850, a period known as the Little Ice Age, one of several cold snaps that briefly interrupted the overall warming trend ongoing since the end of the Ice Age. As the thermometer goes deeper into the ice sheet, the temperature warms again, and then plummets to the temperatures indicative of the Ice Age. Finally, the bottom layers of the ice sheet are warmed by heat coming from the Earth. These directly measured temperatures represent a rough average—a record of trends, not variable, daily temperatures—but climatologists can compare the thermometer temperatures with the oxygen isotope record as a way to calibrate those results.

As valuable as the temperature record may be, the real treasure buried in the ice is a record of the atmosphere’s characteristics. When snow forms, it crystallizes around tiny particles in the atmosphere, which fall to the ground with the snow. The type and amount of trapped particles, such as dust, volcanic ash, smoke, or pollen, tell scientists about the climate and environmental conditions when the snow formed. As the snow settles on the ice, air fills the space between the ice crystals. When the snow gets packed down by subsequent layers, the space between the crystals is eventually sealed off, trapping a small sample of the atmosphere in newly formed ice. These bubbles tell scientists what gases were in the atmosphere, and based on the bubble’s location in the ice core, what the climate was at the time it was sealed. Records of methane levels, for example, indicate how much of the Earth wetlands covered because the abundance of life in wetlands gives rise to anaerobic bacteria that release methane as they decompose organic material. Scientists can also use the ice cores to correlate the concentration of carbon dioxide in the atmosphere with climate change—a measurement that has emphasized the role of carbon dioxide in global warming.

Finally, anything that settles on the ice tends to remain fixed in the layer it landed on. Of particular interest are wind-blown dust and volcanic ash. As with dust found in sea sediments, dust in ice can be analyzed chemically to find out where it came from. The amount and location of dust tells scientists about wind patterns and strength at the time the particles were deposited. Volcanic ash can also indicate wind patterns. Additionally, volcanoes pump sulfates into the atmosphere, and these tiny particles also end up in the ice cores. This evidence is important because volcanic activity can contribute to climate change, and the ash layers can often be dated to help calibrate the timeline in the layers of ice.

Though ice cores have proven to be one of the most valuable climate records to date, they only provide direct evidence about temperature and rainfall where ice still exists, though they hint at global conditions. Marine sediment cores cover a broader area—nearly 70 percent of the Earth is covered in oceans—but they only give tiny hints about the climate over the land. Soil and rocks on the Earth’s surface reveal the advance and retreat of glaciers over the land surface, and fossilized pollen traces out rough boundaries of where the climate conditions were right for different species of plants and trees to live. Unique water and rock formations in caves harbor a climate record of their own. To understand the Earth’s climate history, scientists must bring together all of these scattered threads into a single, seamless story.

References:

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Bradley, R., 1999: *Paleoclimatology,* Academic Press, Harcourt Brace and Company, San Diego, California.

Imbrie, J. and K. P. Imbrie, 1979: *Ice Ages,* Enslow Publishers: Hillside, New Jersey.

**DUE NEXT CLASS: Toprepare for the lab, answer the following questions in your notes in complete sentences.**

**1) From your reading and research, how do scientists learn about Earth’s past from ice sheets and glaciers? What kinds of information do they gather?**

**2) How do scientists estimate temperature and carbon dioxide levels from thousands of years ago, using their ice core analyses?**

**3) How do scientists estimate the age of a given layer in an ice core?**